Our 2012 Off-Grid Solar Electrical System – 30 Years of Evolution, by Bob Dahse

Our first home was electrically powered by a 12-volt “umbilical cord” running from the battery in a late-60's Volkswagen Beetle to a few tiny 12-volt appliances. We would push-start and drive the car 20 miles once each week to get supplies in town and recharge the battery. It was a big upgrade to build our own photovoltaic (PV) panel from thirty-six, 4-inch, silicon cells from an electrical surplus catalog. Our next home used both a recycled wind turbine from the 1930's and solar electricity from purchased PV panels. Our current current house is solely solar powered since a nearby site that's high enough for wind is too far away to economically transport the energy, and stream that could supply hydroelectric power is far below us in the valley, again making the transport distance too far to accomplish without lots of expensive copper cable and protective tubing to keep the squirrels from chewing it up.

While the up-front cost of solar electricity may be the highest of the available alternatives in terms of cost per watt produced, it's the simplest to install, the longest lasting, and the easiest and cheapest to maintain. When your current site is ideal for solar but not the others you have to use what your site dictates! Below is a photograph of our only electric power source: about 1900 watts of solar power manufactured by Kyocera, one of the oldest ceramics companies (and they aren't owned by an oil company!). To see the technical specifications on these panels, just **Click Here**.

The next component in either an “off-grid” power system, with no connection the the local electrical network, or in a system that maintains a renewable source of back-up, emergency power, is batteries. But before the energy flows to the batteries there needs to be some protection added to the system to ensure that a nearby lightning strike doesn't travel into your home along with the desired renewable power. In our home the solar power gets intercepted by this device, a lightning arrestor. It connects to both the positive and negative incoming wires, and shunts any high voltage spikes to a ground cable connected to an outdoor ground rod.

Power can be stored on-site using a variety of battery types including the old lead-acid, deep-cycling variety, improved by better construction, lower maintenance, and longer useful life before recycling. In our current home, we originally used four, 375 amp-hour, 6-volt batteries wired in series-parallel configuration to obtain 12 volts and 750 amp-hours (seen above, at the left, totaling 9.5 kilowatt-hours). Our batteries before that were Thomas Edison's nickel-iron (Ni-Fe) cells using potassium hydroxide electrolyte, manufactured in the 1920's. They were built for severe conditions and industrial use, and could be restored by simply changing electrolyte every 10 years. But we switched to lead-acid mainly because it's getting harder to find replacements for mechanically damaged Ni-Fe cells or to find additional cells. There are Chinese models made now, but the quality is not up to Edison's standards! For some time we were using the set-up shown above, with lead acid wet cells and gel cells in parallel, until the left set was removed. Now we just use the sealed lead-acid gel batteries seen above at the right, 10 batteries, wired in parallel for 12 volts, totaling 980 amp-hours or 12.5 kilowatt-hours. The wet cells were recycled after nearly 10 years of use. Now we have no fluids to add, no gases given off, and twice the battery service life at the same use rate. If you would like to see the specifications of these batteries, just Click Here.

Some of what is now used for home energy systems got its start in the military. This is a close-up of the water-saving battery caps we used in the old lead-acid “wet cells”. Since charging batteries "gas off" some hydrogen and oxygen when they're nearing full charge, various caps have been designed to catalytically recombine the gases to water (HydroCaps, for instance), or simply to condense evaporating water (like these), in systems that don't heavily overcharge. This technology was originally used in WWII submarines which surfaced to quickly diesel-charge their batteries and generated lots of explosive gases in the process.

We also used a device designed for the military called a "desulfator". It uses a tiny bit of battery power to send a small high-frequency pulse back into the batteries, hampering the growth of large lead sulfate crystals that build up on the lead plates, eventually leading to premature battery failure. This rather cramped photo shows the 2-by-2-inch device. Now that we use sealed batteries that do not sulfate these devices have become obsolete in our power system.

In order to keep both the batteries, and anything connected to them, from getting “fried” by too much voltage or starved or sufficient voltage to charge or power them, there needs to be some form of regulation for your incoming power source. In the case of PV panels, the early models had no internal protection from electrical “back-flow” at night. The solution was a simple Shottky diode mounted on a heat-sink. This worked to keep power flowing in one direction but still did not keep voltages in a narrow range.

To accomplish true voltage regulation we originally used this device, a Trace C-30 Voltage Controller. It could switch the PV power on or off, or it could shunt excess power to a “diversion load”, such as a 12-volt water heater element, light bulbs, a 12-volt refrigerator, or simple ceramic resistors (more on these below). It worked well at this task but the frequent clicking of the relays as voltage reached its high and low set-points became annoying and we tried to find something a bit more sophisticated that could charge batteries the way they were designed to be charged, in stages of high current bulk charge, a constant voltage absorbing charge, followed by a lower voltage float rate.

This was our next load diversion controller, a Trace C-40. It used PWM, or Pulse-Width Modulation – a fancy form of switching the inputs on and off at a very rapid rate, to divert the exact amount of excessive input power that keeps the batteries at a specified bulk-charge, absorbing, or float-charge voltage. But with precision came a nasty low-pitched electrical hum from the pulsed DC current sent to the diversion loads. Eventually this had to go in favor of a return to the older C-30 (black box above), and the house was quieter both in terms of sound and electric fields. The unit was sold to someone with a smaller PV system.

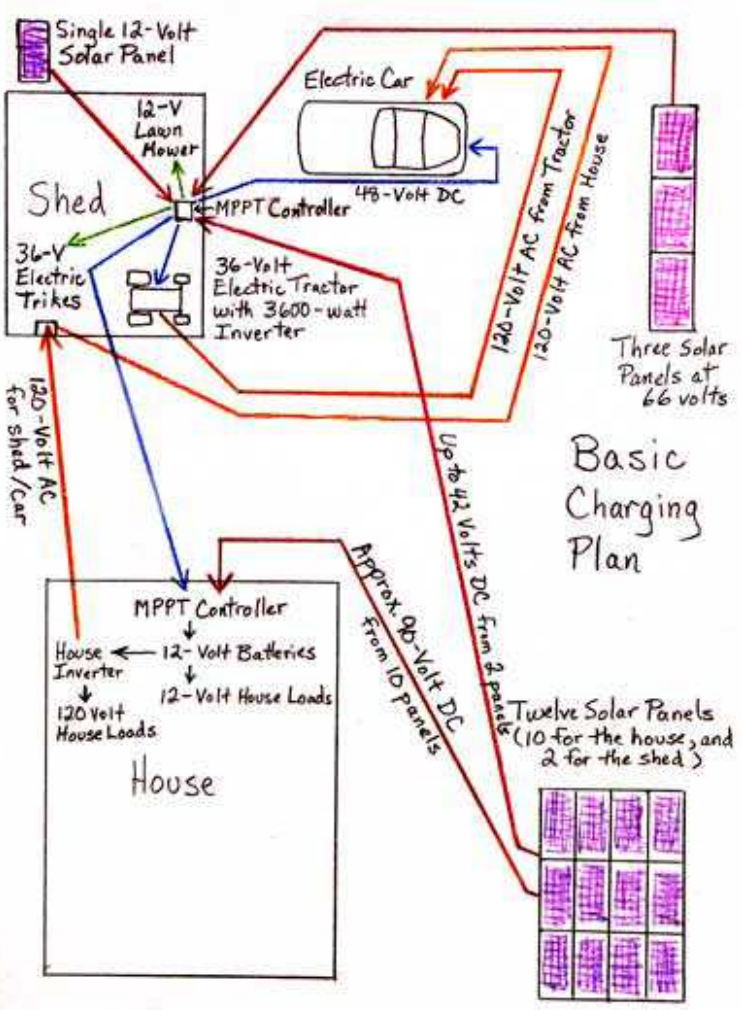
Both of these devices have been replaced by MPPT (maximum power-point tracking) controllers from Outback, the FlexMax-80 and Flexmax-60. They replace all of the functions of a reverse-flow-preventing diode (seen above), a load diversion controller (like the Trace C-30), and a PWM input controller (like the Trace C-40). They can handle up to 60 or 80 amps of power into 12 to 48-volt batteries, maximizing the power input from the PV panels, and have "AUX Send" output terminals to switch external power-control relays on or off at specific voltages. This allows tight control over our power diversion loads, including an electric water heater, 12-volt refrigerator, electric tractor, electric mower, electric hybrid trikes, an electric car, and an electric oven. Plus, these unit log all of the voltage, amperage, and power statistics generated by the PV system, available for viewing up to 128 days later. And, since they can handle many different output voltages, they can be switched to charge both our 12-volt household battery bank as well as the 36-volt electric tractor battery and the electric car’s three 48-volt packs. To see the manual on this product, just click here.

So, at this point power is flowing in safely and it is being stored for future use, with the excess flowing to other appliances, devices, or vehicles that might normally be powered by non-renewable energies. Here are some examples of these so-called diversion loads. This first one is called a ceramic air resistor. It resists the flow of electrical energy and gets hot in the process. This is a useful trait if you want to power a yogurt maker, a small oven, or even a water heater (using a low-voltage stainless steel water-heater element made for the task). The resistors we use can be found on this site, searching under “charge controls” and scrolling far down the page.

We used the 12-volt water heating element in our tiny 10-gallon water heater (right), replacing the standard 120-volt element with the low-voltage unit. The low-voltage oven we built (below) uses four switchable air resistors, two 0.5 ohm and two 5-ohm, to supply either 30, 60, 330, or 660 watts of heat depending on our heating needs. One of the 40-amp, 12-volt relays that turns these diversion loads on and off, based on control signals coming from the Outback controller, is pictured below and right.

Our Servel/Dometic refrigerator is a tiny unit that holds the equivalent of about six 6-packs, It operates from either 120-volt AC power, 12-volt DC power, or from LP (liquified petroleum, or propane) gas, though we use it strictly as a diversion load running at 12 volts at about 7 amps. All of these loads can be switched automatically or chosen manually.

One of the ways in which we switch loads on or off is to use a common electrical breaker box and Square-D brand QO model circuit breakers, which can both safely switch AC/DC loads and act as a resettable fuse. At the left you can see our home's DC breaker box, and below left is our shed's entire control circuitry, switching power manually or automatically from six PV panels to either a 12-volt mower, a 36-volt DC garden tractor, three 48-volt battery banks in our electric Porsche 924, or, as 12-volt, power to our house. The entire wiring plan for the shed is illustrated below.



And shown here are DC switches that choose the refrigerator or the hot water heater, either in manual or auto modes.

But what about devices that run on “normal” 120-volt AC power, you may ask? Well, Our "critical" electrical devices (water pump, lighting, flour mill, radio) run directly from the batteries on 12-volt DC. Previously, our conventional 120-volt appliances ran from the Exeltech XP1100 sine-wave inverter pictured below right. Turning 12-volt DC into 120-volt AC, this inverter easily handled all of our household loads (anything

under 1100 watts, or about 9 amps of AC) but was too small to use with our electric chainsaw or our electric car charger. For these we could use the much larger 3600-watt, “modified-sine-wave" (more on this below) inverter (Tripp-Lite APS3636VR) mounted on our electric tractor, which can power two separate 15-amp AC circuits.

But we now use this 1800-watt Statpower (Xantrex) sine-wave inverter that replaced the Exeltech in our house. We can now operate at least one full 15-amp AC circuit either indoors, in the shed, or outdoors.

Many homes that utilize renewable energy for their electrical needs are wired for both low-voltage DC and standard AC loads. But, since humans are quite sensitive to AC electric and magnetic fields, the inverter is switched on only when AC loads are being operated. We use switched outlets at each appliance location and where a device uses a "black box" or "wall wart" to change voltage or switch from AC to DC current, we use additional labeled wall switches to activate only the intended device. This eliminates "phantom loads," energy sucking, unintended drains on an otherwise intentional, clean, and efficient electrical system.

Since electric fields drop as voltage goes down, 12-volt lighting and appliances are an attractive option where low-power, low-amperage devices can be used. In high-amp loads like big motors or water heaters, the increased magnetic fields these produce can offset any gains made from lowering voltage, unless those loads are far from the main living spaces. In our home, all of the lighting is 12-volt DC. We used to have a few 12-volt compact fluorescent lamps that converted 12 volts of DC to roughly 10,000 volts of AC in the bulb's "ballast" (a tiny inverter). This created a moderately-sized electric field "no-man's-land" around the fixtures as a trade-off for one-fifth the energy use. We have since converted all of our lighting to 12-volt L.E.D. (light emitting diodes) bulbs. For more detail, check our EMF Hazards web page.

Another factor that can reduce or eliminate AC electric/magnetic field exposure is the "sensible" use of an inverter in renewably-powered homes. If the home is not connected to the Grid (by using a grid-intertie inverter), the "stand-alone" inverter turns low-voltage DC from storage batteries into "line-voltage" AC for standard appliances. Since many AC loads can be eliminated by using DC devices wherever possible, the inverter often doesn't have to be running all of the time! And if an inverter should break down (unlikely, but there's always a lightning strike!), powering essential loads direct from battery DC is great insurance.

Older and cheaper "square-wave" and "modified sine-wave" inverters rapidly and abruptly switch voltage levels to create a "choppy" sort of AC that only roughly approximates grid-produced AC. The modern "sine-wave" inverter produces a smoother, wave-like pattern of increasing and decreasing AC voltage that most electrical devices prefer. Not only do motors run cooler on sine waves, but the transformers found in many audio-visual devices and "wall warts" no longer hum. Sine-wave inverters *can* (at least with some modification) actually produce "cleaner" power than what's found on the grid. Grid-produced AC often has voltage spikes, or dips (requiring the use of surge suppressors) and high-frequency "harmonics" (or

"hash") and "transients" (or "spikes") that have additional negative health consequences. But even the best sine-wave inverters also generate harmonic frequencies and internally-generated switching frequencies. What to do about it?

Some inverters constantly check for switched-on loads and turn themselves on only when called for (the Search Mode). And as stated earlier, in our home each cluster of AC outlets has an inverter switch to turn the AC power on only when it's needed. Either way, this eliminates inadvertent AC electric field exposure since no AC is being sent through the wiring most of the time. The Stetzerizer Filters I mention on our EMF Hazards web page don't work well on some inverters. A couple of inverters that seem to be unbothered by the capacitive filtration of the Stetzer filters are the Xantrex {Statpower} Pro-Sine series (seen on the previous page) and the Xantrex SW series.

This is a Graham-Stetzer capacitive filter, composed of a small motor capacitor, a resistor to discharge the capacitor when it is unplugged, a couple of tabs to plug it in, and a plastic case. This one has been modified by adding an aluminum screen around it which gets grounded to the center screw on the outlet face-plate, shielding the home's occupants from high-frequency electric fields that radiate from the capacitor's outer shell. I've contacted the manufacturer about this problem (including electric field readings before and after alteration) and received no response, but this rig works well on some inverters.

But by contacting your inverter's manufacturer, the technical staff may be able to build a frequency-targeted filter specifically designed to remove the unwanted frequencies the unit generates. We did this with a call to Exeltech for our XP1100 inverter. At right is what they sent. We wired it into the inverter's output and enclosed it in a metal box to shield its fields. The Exeltech sees the capacitor in a Graham-Stetzer filter as a challenge to put the voltage and amperage back in synch. This makes for a very unhappy inverter. The solution from Exeltech is lots of induction and very little capacitance. This creates a large localized magnetic field, so the filter they sent is enclosed in a heavy steel box that blocks most of the field. Our newer 1800-watt inverter allows us to use ordinary capacitive filters like the “Stetzerizer”.

That's about it for the moment. We really like having a bit too much PV power on sunny days, just to make sure we have enough on cloudy ones. It gets used to replace lots of non-renewable propane for cooking and water heating, and it keeps our leftovers chilled for reuse. The only improvement at this point would be adding some diversity to our renewable energy inputs, such as a small wind turbine, even though it would be costly in terms of wire length and we don't really need more energy. But when the sun doesn't shine it's often windy, and folks with stream power to harvest often have a very constant day/night energy supply.